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OFFICE OF EXPERIMENT STATIONS—BULLETIN 201.

A. C. TRUE, Director.

COST OF PUMPING FROM WELLS FOR THE IRRIGATION OF RICE IN LOUISIANA AND ARKANSAS.

BY

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WASHINGTON:

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1908.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Office of Experiment Stations,
Washington, D. C., July 6, 1908.

Sir: I have the honor to transmit herewith a report of partial tests of pumping plants used to raise water from wells in Louisiana and Arkansas for the irrigation of rice. The tests were made by Prof. W. B. Gregory, of Tulane University. In many sections where rice is extensively grown the rice growers have the option of purchasing water from a canal company or installing their own pumping plants. One of the main objects of the tests here reported is to supply data which will enable rice growers to decide intelligently which one of these sources of water supply they should employ. The data given in this report would also enable prospective rice growers to determine in advance the probable cost of raising water. In the descriptions of the plants tested many suggestions of improvements are made which should be very valuable to the owners of these and other plants.

It is recommended that this report be published as a bulletin of this Office.

Respectfully,

A. C. True,
Director.

Hon. James Wilson,
Secretary of Agriculture.

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COST OF PUMPING FROM WELLS FOR THE IRRIGATION OF RICE IN LOUISIANA AND ARKANSAS.

INTRODUCTION.

The greater part of the land devoted to the growth of rice in Louisiana and Texas is irrigated with water raised from streams by large pumping plants and supplied to growers under contracts, the usual rate being one-fifth of the crop. The general provisions of these contracts are as follows: A canal company agrees to furnish a sufficient supply of fresh water for a described tract of land, but is not liable for damage on account of shortage. The water is distributed by the company, which has full control as to the manner of distributing water both to and upon the land and is to be the sole judge of the time when water should be supplied. If the planter wastes water from any cause the company may shut off the supply without forfeiting its right to one-fifth of the crop. In case of sufficient rainfall to mature a crop and the planter draws little water from the company the latter is still entitled to its share of the crop. While the extreme case just cited is never realized in actual practice, the fact remains that the demand for water varies greatly with different seasons.

In part to avoid the provisions of these contracts and have an independent supply and in part to cover lands not reached by the large canals, many growers have put down wells and installed their own pumping machinery. For several years the author has been making pump tests in the rice districts, the results of which have been published in previous reports,[a] but with few exceptions the plants tested have been the large ones taking water from streams and bayous; that is, those furnishing water to planters under contracts such as described above. During the season of 1907, however, the small pumping plants lifting water from wells for the use of the owners received special attention. This was done for the purpose of determining the cost of water supplied in this way and in general the efficiency of the methods and machinery used.

It was not possible to make complete mechanical tests of most of the plants visited, as they were not arranged in such a way that the

[a] U. S. Dept. Agr., Office of Experiment Stations Buls. 158, pp. 509–544; 183.

lift could be measured exactly, but the tests made furnished data which are of value in determining the advantages of the well-pumping plants, and should enable planters to determine whether it is to their advantage to take water from a canal or put in their own plants.

INSTRUMENTS USED.

The instruments used and the methods employed were similar to those used in 1905 and 1906. The instruments were in part furnished by the Office of Experiment Stations of the U. S. Department of Agriculture, while others were loaned by Tulane University. Among the former were two steam-engine indicators having reducing wheels, a current meter, and a 50-foot steel tape. The instruments loaned consisted of a Pitot tube, hook gauge, pressure and vacuum gauges, revolution counters, hydrometers, and thermometers.

The springs of the steam-engine indicators, the gauges, and the thermometers were calibrated in the experimental engineering laboratory of Tulane University. The rating of the current meter was furnished by this Department, while the Pitot tube was made of such form that its constant was known to be unity. In a few cases weirs were used to measure the water discharged by the pumps; the weirs were usually of the Cipolletti form.

The Pitot tube was used in one case to traverse pipes to obtain mean velocity. Readings from the Pitot tube were taken in feet of water. The current meter was used to measure discharge in flumes.

METHODS PURSUED.

In making tests of pumping plants the following observations were taken where practicable, exceptions being noted in the descriptions of individual tests: (1) Amount of fuel used; (2) the amount and temperature of water fed to the boilers and the steam pressure; (3) the indicated horsepower of the engine, obtained from the indicator cards and revolutions per minute of engine; (4) the height through which the water was lifted, as nearly as this could be determined; and (5) the volume of water pumped per unit of time. The cost of fuel was also obtained, and in some cases numerous other readings of minor importance were taken; they are given in the logs of tests.

The specific gravity of the fuel oil was taken with a hydrometer. Fuel oil is bought on a basis of measurements of 42 gallons per barrel, no correction being made for differing temperatures. In most cases the oil was measured in carefully calibrated barrels. In a few instances it was measured by the fall in level in a cylindrical tank. Three hundred and twenty pounds were used as one barrel.

The height through which the water was lifted was obtained by direct measurement. In the test of well plants the head used was

the distance from the level at which the water stood in the discharge pipe or suction pipe while the pump was not in operation to the point to which the pump elevated it. In some cases the pumps had been running for several days and were stopped only long enough to measure the head, in one case the head was measured before and after the test, while in others the pumps had not been running for some time and the measurements were made before starting. In all cases, except those in which the pumps had not been running for several days, it is probable that the measurements show very closely the actual lift. More will be said on this point under the description of individual tests.

In the large irrigation plants the discharge from the pumps was measured in the discharge flume or discharge pipe by means of the current meter or Pitot tube. The method is given in each case in detail.

The fuels used in the tests were crude oil, coal, and wood. In Louisiana the price of fuel oil has advanced in the last year to a point where it has to compete with coal. In some localities wood is the fuel used; it is often used with coal. On account of the varying cost of fuel in Louisiana and Arkansas the cost of pumping is quite different; however, this is only one, although usually the most important, of the factors entering into the cost of pumping. In the description of the plants will be found the price of fuel, cost of pumping, and all available information regarding the sizes of the various boilers, engines, pumps, and wells used, together with the types of machines used.

In testing centrifugal pumps submerged in wells it is desirable to know the suction head against which the pump is operating. As the pumps are often submerged in water and as no provision has been made for attaching a vacuum gauge to the suction pipe, it was impossible to obtain the suction head. With well pumps the distance from the surface of the water in the well to the point to which water was lifted, measured as stated above, was used in computing the useful work of the pump. This fact must be kept in mind in comparing the efficiencies of the plants tested with efficiencies claimed by pump builders and with efficiencies obtained elsewhere. The heads actually developed by the pumps when in operation were of course greater than the heads used, since the pumps drew the water down distances which were undetermined in most cases and in no case does the head used include friction. It is greatly to be regretted that these pumps are not provided with vacuum gauges attached to their suction pipes. Without them it is impossible to segregate the efficiencies of the engines, pumps, and wells, and, therefore, where a poor showing is made the tests do not indicate where the fault lies. With suction and pressure gauges and arrangements for measuring the level of the

water while a pump is running, the efficiency of each element of the plant may be determined, thus locating any defects. Owners of pumping outfits should insist, wherever practicable, on having the gauges as parts of the equipment of new plants. Manufacturers and contractors ought to be interested in supplying the instruments, in order that they may know more exactly what their machinery is doing and so be in position to design each new plant with a full knowledge of conditions.

As it is, a low efficiency in any case may indicate either that the engine or pump is not working properly, that there is not sufficient strainer capacity, or that the well does not supply sufficient water for the pump.

In the description of plants tested will be found all the points of interest regarding each plant. The differences in types of machinery and in conditions of operation are also noted.

DESCRIPTION OF PLANTS AND RESULTS OF TESTS.

In general, the tabulated results are self-explanatory. The attempt is made to bring out the facts of greatest interest to the owners of pumping plants, and especially the cost of pumping. Measurements covering several years show that the average quantity of water used on rice is about 15 inches in depth over the land during the growth of a crop, and this depth has been used in computing the cost of pumping per acre irrigated. No data showing the cost of attendance and other labor employed in pumping were collected. This is considerable, as the plants are operated night and day for sixty to one hundred days each year, taking practically all of the time of two men, who receive from $1.50 to $2 per day. This makes an average cost of perhaps $3.50 per day for attendance. Assuming an average season of eighty days makes this cost $280 for each plant. In each case this sum is divided by the number of acres, to secure the cost of attendance per acre.

Interest is assumed at 7 per cent, and depreciation at 10 per cent of the first cost. Interest, depreciation, attendance, and fuel cost for 1.25 acre-feet, or 15 acre-inches, are added to secure the annual cost of pumped water per acre irrigated.

PLANT NO. 1.

The plant of Mr. H. E. Wesson, located about one-half mile northeast of the railway station at Welsh, La., was tested on June 17, 1907. This same plant was tested in 1905. The engine and boiler used at that time were still in use in 1907, but the well and pump had been changed. The new well is 335 feet deep; it has a 10-inch casing with 80 feet of strainer, consisting of wire of trapezoidal cross section wound over a pipe through which numerous holes had been drilled. The new pump is a No. 6 compound vertical centrifugal. It was driven

by a quarter-twist belt. The engine fly wheel is 60 inches in diameter and the pulley on the pump 18 inches in diameter. This pump is peculiar in that no pit is required except the steel casing above and fastened to the pump, of the same diameter as the largest diameter of the pump (fig. 1). A hole of the proper diameter is bored into the ground to a depth sufficient to submerge the impellers of the pump. This hole is approximately three times the diameter of the casing below. With this type of pump alignment of shaft is insured. The pump was placed 40 feet below the surface.

The boiler is of the locomotive type, having seventy-two 2-inch flues 9 feet long, and has a capacity, according to the builders' rating, of 50 horsepower.

The engine is a simple noncondensing, slide-valve, and has a cylinder 12 inches in diameter and stroke of 15 inches. There is a feed-water heater in the base of the engine. The boiler was fed by a pump. The feed water used during the test was weighed.

The fuel used was crude oil, costing $1.40 per barrel of 42 gallons at the plant. During the test it was measured in an elevated tank by noting the fall of level. The specific gravity was determined by means of a hydrometer.

The cost of this plant was as follows:

Engine, boiler, and shed	$1, 175
Belt	50
Well, pump, and derrick, including steel pit	2, 074
Total	3, 299

The plant was in fairly good condition, as the engine had received a general overhauling and had been placed on a new foundation.

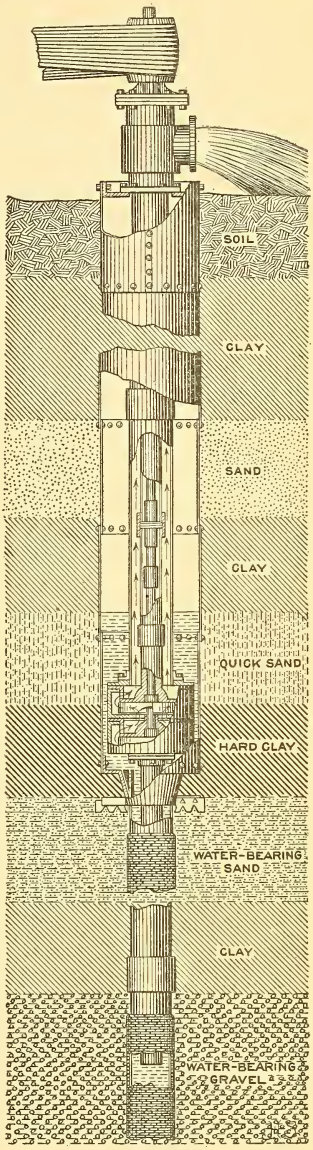

FIG. 1.—Arrangement of centrifugal pump without pit.

The water pumped was measured by means of a weir $36\frac{1}{8}$ inches in width with end contractions suppressed; the depth over the crest of the weir was measured by means of a hook gauge.

It was impossible to measure the depth of water in the well even when the pump was not running; however, there was an old well about 75 yards away in which the depth could be measured. The water in the old well and in the new one was known from previous observations to be at the same level.

As already stated, the useful work credited to the pump was computed on the basis of the height from the level of water in the well when the pump was not running to the level at which it was discharged. It must be remembered that the true head was greater than the head used. The water in this well is lowered when the pump is started, and there is a loss of head in passing through the screen and some loss in the suction pipe below the pump. The only way the true head can be known is by attaching a vacuum gauge to the suction pipe underneath the pumps, and this was impossible. The efficiency given might be termed the efficiency of engine, pump, and well, charging the lowering of the water and loss in the screen to the well.

There was a comparatively small amount of heat added to the water at the feed-water heater, because the steam merely enters the heater and emerges from the point of entry. This arrangement could be improved by having the exhaust pipe taken out at a point which would compel the steam to travel along the outside of the pipes containing water in the heater.

Results of test of plant No. 1.

Duration of test, hours	4.67
Lift, feet	11.60
Average indicated horsepower	42.3
Average discharge of pump, cubic feet per second	3.21
Average discharge of pump, gallons per minute	1,444
Average discharge of pump, acre-feet per hour	0.265
Fuel consumed per hour, pounds	207
Fuel consumed per indicated horsepower hour, pounds	4.89
Fuel consumed per acre-foot, pounds	781.1
Fuel consumed per foot-acre-foot, pounds	67.3
Cost of fuel per barrel	$1.40
Cost of fuel per hour	$0.906
Cost of fuel per indicated horsepower hour	$0.0214
Cost of fuel per acre-foot	$3.42
Cost of fuel per foot-acre-foot	$0.294
Efficiency of engine, pump, and well, per cent	10

COST OF WATER.

Cost of plant	$3,299

PLANT NO. 2.

The well-pumping plant of Mr. John H. Armstrong, located about 3 miles southeast of Welsh, La., was tested on June 18, 1907. It was used to water 140 acres during the season of 1907.

The well is $9\frac{5}{8}$ inches in diameter and 305 feet deep. The pit is 35 feet deep and there are 82 feet of sawed strainer (fig. 2).

The pump used is a No. 6 vertical-shaft centrifugal with a 14-inch pulley.

The engine is a slide-valve; diameter of cylinder, $9\frac{1}{8}$ inches; stroke, 12 inches; diameter of rod, $1\frac{7}{16}$ inches. The exhaust of the engine passed through a closed heater to the smokestack. The fly wheel of the engine to which the pump is belted is 40 inches in diameter.

The boiler is of the locomotive type, with fiftv-two tubes 12 feet in length and 3 inches in diameter. The builders' rating of boiler is 60 horsepower. A feed-water heater utilized a part of the heat of the exhaust steam that otherwise would have been thrown away. A small, direct-acting steam pump is used to feed the boiler. The mean temperature of water coming from the well was 80° F., while the mean temperature of the water after passing through the heater was 188.5° F. The saving of fuel by the use of the heater in this case was 9.5 per cent.

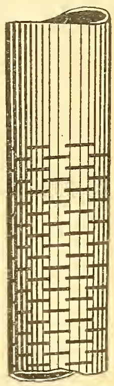

Fig. 2.—Sawed strainer.

The importance of a heater in a small pumping plant is too often overlooked. An inexpensive one can be made of pipe fittings; in the average case a heater will save about 10 per cent of the fuel, and at the present prices for fuel so large a saving is well worth while. Feed water was measured during the test by weighing.

Indicator cards and general observations were taken every half hour.

Coal was carefully weighed and the time noted for using each 100 pounds. The fuel used was bituminous coal, costing $5.70 per ton of 2,000 pounds at the plant.

The discharge was measured by means of a current meter in a small flume built in the discharge ditch for that purpose.

The height through which the water was raised was measured in an abandoned well near the one in use, as in the case of the test plant No. 1. The height from water surface to level of discharge was the head used in computing useful water horsepower.

The cost of this plant complete, including engine, boiler, belts, foundations, heater, and feed pump, well pump, pit, well, lumber, strainer pipe, and shed, was $2,668.

Some trouble was encountered because of the slipping of the cotton belt, and during the test the belt lacing broke and had to be repaired. Otherwise the test was entirely satisfactory.

The pump is provided with an appliance for maintaining alignment of shaft. Briefly, it consists of special pipe fittings by means of which the discharge pipe of the vertical-shaft centrifugal pump is brought

over near the shaft and then carried up parallel to the shaft. The pipe is screwed home very solidly into the fittings so that it is rigid. Special bearings for the shaft are then clamped to the pipe. Any settling of the pump or change of position results in a corresponding change in the discharge pipe and shaft so that the alignment is maintained.

The results of the test follow:

Results of test of plant No. 2.

Duration of test, hours	4
Lift, feet	17.5
Average indicated horsepower	48.95
Average discharge of pump, cubic feet per second	4.55
Average discharge of pump, gallons per minute	2,050
Average discharge of pump, acre-feet per hour	0.376
Fuel consumed per hour, pounds	212.5
Fuel consumed per indicated horsepower hour, pounds	4.34
Fuel consumed per acre-foot, pounds	565.2
Fuel consumed per foot-acre-foot, pounds	32.3
Cost of fuel per ton	$5.70
Cost of fuel per hour	$0.608
Cost of fuel per indicated horsepower hour	$0.0124
Cost of fuel per acre-foot	$1.62
Cost of fuel per foot-acre-foot	$0.092
Efficiency of engine, pump, and well, per cent	19.2
COST OF WATER.	
Cost of plant	$2,668
Area irrigated, acres	140
Cost of plant per acre irrigated	$19.06
ANNUAL COST PER ACRE.	
Interest on first cost at 7 per cent	$1.33
Depreciation, 10 per cent on first cost	1.91
Fuel cost of 1.25 acre-feet	2.03
Attendance	2.00
Total annual cost per acre irrigated	7.27

PLANT NO. 3.

The pumping plant owned by Mr. M. A. Neely and located about 4 miles north of Welsh, La., was tested on June 20, 1907. During the season of 1907 about 300 acres of rice was irrigated.

The engine is a simple, noncondensing, slide-valve, with dimensions as follows: Diameter of cylinder 11 inches, stroke 14 inches, diameter of rod $1\frac{1}{16}$ inches. From the fly wheel of the engine power is transmitted to the pump by means of a rope drive consisting of four strands of $1\frac{1}{4}$-inch manila rope. The driving sheave on the engine is 69 inches in diameter and that on the pump 21 inches in diameter.

The pump is a vertical-shaft centrifugal, in a pit about 30 feet deep. The well has a depth of 325 feet; 80 feet of strainer is used. It is of the usual type made by drilling holes in the casing and then wrapping it with wire.

The boiler is a horizontal, return-tubular, rated by the builders at 50 horsepower.

The fuel used was crude oil from the Jennings field, costing $1.40 per barrel at the plant. During the test the height of oil in a cylindrical tank was noted and at the end of the test the same level was restored by adding a weighed quantity of oil to the tank.

Feed water is forced through a heater by the steam pump used to feed the boiler.

The water discharged by the pump was measured by means of a current meter in a small flume leading from the pond in which the pump discharged to the small canal used to convey the water to the field.

Indicator cards and other observations were taken at half-hour intervals; the duration of the test was four hours. The level of the water in the discharge pipe could be observed when the pump was not running by letting down a lantern. The distance from this level to the point to which the water was discharged was used as the head in computing useful water horsepower and efficiency.

The cost of the entire outfit, including boiler, engine, pump, well, belt, and shed, was $2,200.

The results of the test follow:

Results of test of plant No. 3.

Duration of test, hours	4
Lift, feet	23.86
Average indicated horsepower	53.7
Average discharge of pump, cubic feet per second	4.34
Average discharge of pump, gallons per minute	1,953
Average discharge of pump, acre-feet per hour	0.359
Fuel consumed per hour, pounds	191.8
Fuel consumed per indicated horsepower, pounds	3.57
Fuel consumed per acre-foot, pounds	531.5
Fuel consumed per foot-acre-foot, pounds	22.3
Cost of fuel per barrel	$1.40
Cost of fuel per hour	$0.84
Cost of fuel per indicated horsepower hour	$0.0157
Cost of fuel per acre-foot	$2.34
Cost of fuel per foot-acre-foot	$0.098
Efficiency of engine, pump, and well, per cent	21.8

COST OF WATER.

Cost of plant	$2,200
Area irrigated, acres	300
Cost of plant per acre irrigated	$7.33

ANNUAL COST PER ACRE.

Interest on first cost at 7 per cent	$0.51
Depreciation, 10 per cent of first cost	.73
Fuel cost of 1.25 acre-feet	2.93
Attendance	.93
Total annual cost per acre irrigated	5.10

PLANT NO. 4..

The plant owned by Mr. L. E. Robinson, located about 7 miles northeast of Welsh, La., was tested on June 22, 1907. It was a new outfit, used for the first time during the season of 1907, when about 230 acres was watered.

The plant is equipped with a heavy-duty, noncondensing slide-valve engine, with dimensions as follows: Diameter of cylinder $12\frac{1}{32}$ inches, stroke 20 inches, diameter of rod $1\frac{15}{16}$ inches. The fly wheel is 60 inches in diameter; a quarter-turn belt is used to transmit power from the engine to a No. 10 centrifugal pump, similar to that described in test No. 1, having a discharge pipe 12 inches in diameter. The well has a casing 18 inches in diameter, is 320 feet deep, and has 105 feet of strainer. The pit is 50 feet deep.

The boiler is of the locomotive type, with seventy-nine 3-inch tubes 13 feet long.

Fuel oil was used. It was stored in a vertical cylindrical tank. The distance from the rim of the tank to the surface of the oil was observed every hour, and the weight of oil computed from these readings and the specific gravity. As the oil used during the test had been placed in the tank from which it was fed by gravity to the burner only a short time previous to the test, it is probable that some water was still mixed with it, as sufficient time had not been allowed for it to settle. The exhaust pipe of the small steam pump used to feed the boiler was run through the fuel oil tank and by this means the temperature of the oil was raised to 103° F.

The discharge of the pump was measured by placing a plank, beveled on the downstream side and with a sharp corner on the upstream side, across the flume below the pump, to act as the sill of a weir without end contractions. There was quite a large velocity of approach which was taken into account in computing the quantity of water. A hook gauge was used to measure the depth of water over the sill of the weir.

The water fed to the boiler was carefully measured by means of a calibrated barrel, which was filled by means of a hand pump and then allowed to empty into a barrel below, from which it was pumped to the boiler. There was a heater in which the water had its temperature raised from about 75° F. to 175° F.

During the test readings of the hook gauge were taken every fifteen minutes; indicator cards and general observations were taken every half hour. The quantity of oil used was measured every hour.

The level of the water in the well was found by means of a steel tape let down into the discharge pipe. Before the test was started the observed depth was 26.5 feet below the level of discharge, while at the end it had increased to 27.5 feet; the mean of the two was used as the head in computing useful water horsepower.

The cost of the outfit was as follows:

Engine and boiler, feed pump, piping, etc	$1, 500
Well, pit and pump, set up	2, 304
Shed	600
Total	4, 404

The results of the test follow:

Results of test of plant No. 4.

Duration of test, hours	4
Lift, feet	27
Average indicated horsepower	47. 2
Average discharge of pump, cubic feet per second	2. 78
Average discharge of pump, gallons per minute	1, 251
Average discharge of pump, acre-feet per hour	0. 231
Fuel consumed per hour, pounds	240. 8
Fuel consumed per indicated horsepower hour, pounds	5. 10
Fuel consumed per acre-foot, pounds	1, 042. 4
Fuel consumed per foot-acre-foot, pounds	38. 6
Cost of fuel per barrel	$1. 05
Cost of fuel per hour	$0. 79
Cost of fuel per indicated horsepower hour	$0. 0168
Cost of fuel per acre-foot	$3. 43
Cost of fuel per foot-acre-foot	$0. 127
Efficiency of engine, pump, and well, per cent	18. 4
COST OF WATER.	
Cost of plant	$4, 404
Area irrigated, acres	230
Cost of plant per acre irrigated	$19. 15
ANNUAL COST PER ACRE.	
Interest on first cost at 7 per cent	$1. 34
Depreciation, 10 per cent of first cost	1. 92
Fuel cost of 1.25 acre-feet	4. 25
Attendance	1. 22
Total annual cost per acre irrigated	8. 73

PLANT NO. 5.

The pumping plant of Mr. W. S. Robertson, located about 2 miles east of the town of Iota, La., was tested on June 26, 1907. This plant watered 175 acres of rice during the season of 1907.

The plant is equipped as follows: There is a simple, slide-valve, noncondensing engine, with diameter of cylinder 10 inches, length of stroke 12 inches, and diameter of rod $1\frac{1}{2}$ inches. The engine is direct-connected to a rotary pump having a capacity of 13.6 gallons per revolution. The engine and pump are placed in a pit about 10 feet deep. The pump has its suction side connected to two 10-inch wells, each 200 feet deep and about 40 feet apart. The pump is between the two wells, about 20 feet from each. The discharge pipe of the pump is 12 inches in diameter. The suction pipes are provided with wire-gauze strainers of unknown length. The plant has been operated for five years.

The boiler used is of the locomotive type, rated by its builders at 25 horsepower. Water is fed to the boiler by means of an injector.

The fuel ordinarily used is coal and wood. The cost of the former is $6.35 per ton and of the latter $2.25 per cord at the plant. During the test coal only was used, so that the measurement of fuel could be made more definitely. Coal was weighed up in quantities of 40 pounds and the time noted when each charge was fired.

The water pumped was measured in a small flume by means of a current meter.

Indicator cards, readings of steam pressure, temperature, and observations with the current meter were taken at half-hour intervals.

The true head pumped against was determined in this case by placing a vacuum gauge on the suction pipe. Measuring the head from the point where the gauge was attached to the level of discharge and adding it to the vacuum expressed in feet of water gave the head against which the pump was actually operating.

It was impossible to directly measure the depth of water in the well, as the tees at the top of the well casing into which was screwed the pipe leading from the well casing to the pump were both several feet under ground. Previous to 1907 the pump and engine had been at the surface of the ground. The flanges forming covers for the top of the tees had often been taken off the tees and the depth measured and compared to the depth observed by neighbors in the discharge pipes of centrifugal pumps at a distance of a mile or two from the wells tested, and it was found that they always agreed within a few inches. At the time the test was made, the level of water in the same neighbors' wells was known to be about 20 feet from the surface, and therefore that head was used as the basis for computing useful water horsepower, in order that a comparison could be had between the centrifugal pumps and the rotary. By consulting the summary of results it will be seen that the efficiency on the same basis as that used for all other pumps is 50 per cent better than the best one of any other class. This accords with the efficiencies found for large pumps of this type. By consulting the table showing the cost of pumping it will be seen that this plant made a good showing, in comparison with

others, as to fuel economy. A feed-water heater would reduce the fuel bill by about 10 per cent, and ought to be added to the equipment of this plant.

The total cost of this plant complete, including boiler, engine, pump, wells, piping, etc., was $3,300.

Results of test of plant No. 5.

Duration of test, hours	4
Lift, feet	33.25
Average indicated horsepower	21.9
Average discharge of pump, cubic feet per second	3.19
Average discharge of pump, gallons per minute	1,436
Average discharge of pump, acre-feet per hour	0.265
Fuel consumed per hour, pounds	120
Fuel consumed per indicated horsepower hour, pounds	5.48
Fuel consumed per acre-foot, pounds	452.8
Fuel consumed per foot-acre-foot, pounds	13.62
Cost of fuel per ton	$6.25
Cost of fuel per hour	$0.376
Cost of fuel per indicated horsepower hour	$0.0172
Cost of fuel per acre-foot	$1.42
Cost of fuel per foot-acre-foot	$0.071
Efficiency of engine, pump, and well, per cent	[a] 55
COST OF WATER.	
Cost of plant	$3,300
Area irrigated, acres	175
Cost of plant per acre irrigated	$18.86
ANNUAL COST PER ACRE.	
Interest on first cost at 7 per cent	$1.32
Depreciation, 10 per cent of first cost	1.89
Fuel cost of 1.25 acre-feet	1.78
Attendance	1.60
Total annual cost per acre irrigated	6.59

PLANT NO. 6.

The plant owned by Mr. Henry Schambaugh, located near the town of Iota, La., about a mile distant from the plant described as plant No. 5, was tested on June 27, 1907. One hundred and forty acres of rice was watered in 1907.

The engine is a noncondensing slide-valve, with dimensions as follows: Diameter of cylinder 11 inches, stroke 13 inches, diameter of rod 1½ inches. The fly wheel, 50 inches in diameter, drives a vertical shaft centrifugal pump by means of a quarter-twist belt. The diameter of the pulley on the pump is 14 inches.

The boiler is of the locomotive type, having fifty-four tubes 2½ inches in diameter by 8 feet 3 inches long, rated by its builders at

[a] With the lift estimated at 20 feet, to correspond with other plants, the efficiency is 33.4 per cent.

40 horsepower. It is well lagged with sheet metal arranged to leave a space over the surface which is filled with charcoal.

A pump is used to feed the boiler. The feed water is forced through a heater in the engine base, into which the engine exhausts. In this way the feed is heated from an average temperature of 84° F. to 147° F.

The fuel used was crude oil, costing $1.40 per barrel of 42 gallons at the plant.

The pump is a No. 6 vertical shaft centrifugal, having suction and discharge pipes each 10 inches in diameter. The well is 315 feet deep and the pit 38 feet deep. Both sawed and wire-wound screens were used in the 60 feet of strainer.

The water pumped was measured by means of a current meter in a flume about one-fourth mile distant from the pumping plant. Although the test lasted for four hours, the water measurement was taken only during the last two hours.

Fuel oil was measured at half-hour intervals by the drop in level in a vertical cylindrical tank from which the burner is fed by gravity.

Indicator cards, readings of current meter, and the other observations were taken at intervals of a half hour.

The distance between the water level when the pump was still and the level of discharge was measured by means of a steel tape in the discharge pipe of the pump. This height was used as the head in computing useful water horsepower and efficiency. The pump had been running for some time and was stopped only long enough to make the measurement.

The cost of the entire plant was $2,500.

Results of test of plant No. 6.

Duration of test, hours	4
Lift, feet	21
Average indicated horsepower	38.6
Average discharge of pump, cubic feet per second	3.30
Average discharge of pump, gallons per minute	1,485
Average discharge of pump, acre-feet per hour	0.274
Fuel consumed per hour, pounds	133.3
Fuel consumed per indicated horsepower hour, pounds	3.45
Fuel consumed per acre-foot, pounds	486.5
Fuel consumed per foot-acre-foot, pounds	23.17
Cost of fuel per barrel	$1.40
Cost of fuel per hour	$0.585
Cost of fuel per indicated horsepower hour	$0.0152
Cost of fuel per acre-foot	$2.14
Cost of fuel per foot-acre-foot	$0.102
Efficiency of engine, pump, and well, per cent	20.3

COST OF WATER.

Cost of plant	$2,500
Area irrigated, acres	140
Cost of plant per acre irrigated	$17.86

ANNUAL COST PER ACRE.

Interest on first cost at 7 per cent	$1.25
Depreciation, 10 per cent of first cost	1.79
Fuel cost of 1.25 acre-feet	2.68
Attendance	2.00
Total annual cost per acre irrigated	7.72

PLANT NO. 7.

The plant owned by Mr. T. J. Curtis, tested on July 9, 1907, is located about 3 miles northwest from Gueydan, La. During the season of 1907 about 165 acres of rice was watered.

The engine is a slide-valve, noncondensing, with dimensions as follows: Diameter of piston 11 inches, stroke 14 inches, diameter of rod $1\frac{1}{16}$ inches.

The boiler is of the locomotive type and contains forty-eight 3-inch flues 11 feet 9 inches long. The length of boiler over all is 18 feet and the diameter of the front portion 45 inches. The builders' rating is 50 horsepower.

The pump is a vertical-shaft centrifugal, with a 6-inch discharge pipe. A quarter-twist belt from the engine fly wheel drives the pump.

The well is 10 inches in diameter and 238 feet deep, with 80 feet of wire-wound screen. Of this, 60 feet is wound with galvanized and 20 feet with copper wire.

The fuel used was coal, costing $6.75 per ton of 2,000 pounds at the plant.

An injector is used to feed the boiler. There was no feed-water heater. The feed water was measured in a calibrated barrel.

The discharge was measured by means of a current meter in a small flume. Readings were taken at half-hour intervals.

Coal was weighed out in 30-pound quantities and the time of firing each charge was noted.

Indicator cards and other readings were taken at half-hour intervals.

The cost of the outfit is given in detail in the following statement:

Engine, boiler, and pump	$1,562.00
Well, 238 feet deep, at $3	714.00
Strainer	80.00
Lumber for pit	16.00
Digging pit	16.00
3 hoops for pit	9.00
160 feet lumber for pump frame	3.20
Cost of setting pump	12.50
Cost of unloading boiler from car	5.00
Hauling pump, boiler, and engine	14.00
3,000 brick	30.00
3 barrels cement	12.00
Labor for setting engine	50.00
Total	2,523.70

When the pump was idle for some time the level of the water was only 7.81 feet below the height to which it was elevated when the pump was running. Water stands quite near the surface in the Gueydan district, as it is much nearer the Gulf of Mexico than the wells previously tested, and the level of the ground surface is lower than it is farther north. At first glance it would seem as though the pumping of water in this territory would be much less expensive than in sections where the distance from water surface to ground level is much greater. The advantage, however, is lost when the wells are pumped to nearly their full capacity. The hydraulic gradient in the immediate vicinity of the well falls from this cause as well as from the loss of head in flowing through the gravel, so that the original height as observed may be only a small portion of the total head when the pump is running at full capacity, and therefore the head as observed and used in these tests may be only a small part of the total head.

Results of test of plant No. 7.

Duration of test, hours	4
Lift, feet	7.81
Average indicated horsepower	32
Average discharge of pump, cubic feet per second	3.77
Average discharge of pump, gallons per minute	1,695
Average discharge of pump, acre-feet per hour	0.313
Fuel consumed per hour, pounds	172.5
Fuel consumed per indicated horsepower hour, pounds	5.39
Fuel consumed per acre-foot, pounds	551.1
Fuel consumed per foot-acre-foot, pounds	70.6
Cost of fuel per ton	$6.75
Cost of fuel per hour	$0.583
Cost of fuel per indicated horsepower hour	$0.0182
Cost of fuel per acre-foot	$1.87
Cost of fuel per foot-acre-foot	$0.24
Efficiency of engine, pump, and well, per cent	10.5

COST OF WATER.

Cost of plant	$2,524
Area irrigated, acres	165
Cost of plant per acre irrigated	$15.30

ANNUAL COST PER ACRE.

Interest on first cost at 7 per cent	$1.07
Depreciation, 10 per cent of first cost	1.53
Fuel cost of 1.25 acre-feet	2.34
Attendance	1.71
Total annual cost per acre irrigated	6.65

PLANT NO. 8.

On July 10, 1907, a test was made of the pumping plant of Mr. J. W. Gardiner, located about 3 miles south of Gueydan, La. It furnished water to irrigate 200 acres of rice in 1907.

The equipment of this plant was as follows: A slide-valve, non-condensing engine; size of cylinder 14 by 20 inches with piston rod $1\frac{1}{16}$ inches in diameter.

The engine is belted to a jack shaft about 25 feet long from which power is transmitted by quarter-twist belts to two vertical shaft No. 6 contrifugal pumps, one for each of the two wells. The depth of wells is 230 and 233 feet, and the diameter of the casing in each case 10 inches, with 60 feet of wire-wound strainers at the lower end. The wells are 100 feet apart. The pits were comparatively shallow, only about 20 feet deep.

The boiler is of the locomotive type, having a length of 18 feet and a diameter of 54 inches. There are seventy-six 3-inch flues 13 feet in length.

Feed water is pumped into the boiler direct by means of a small steam pump; the mean temperature was 73° F. During the test it was impossible to measure the feed water, and as the plant was in bad condition it was not of much importance that the feed be measured. There were several leaks about the ends of tubes from which the water was running in little streams into the fire box. There were also several leaks in the steam main and the engine was in need of adjustment. A leak in the suction pipe of one of the pumps necessitated the flooding of the pit and doubtless reduced efficiency to some extent.

It was intended to run the test for four hours, but at the end of two hours the main belt broke, necessitating a shut down for about a half hour, so the test was concluded at the end of the two-hour period.

The fuel used was Pittsburg bituminous coal, costing $7 per ton of 2,000 pounds at the plant. The coal was carefully weighed during this time. The revolutions per minute of engine and one of the pumps were observed. As the pulleys on the jack shaft and pump were the same in both cases the revolutions of the pump, neglecting slip, were identical.

The discharge from both pumps was measured by means of a current meter in a small flume.

The test was in every way satisfactory. However, it is probable that observations as to the fuel used for a longer period of time would have given a slightly more reliable result, but, considering the condition of the plant, further efforts in this direction were unwarranted.

Again, as in the case of test No. 7, the water was near the surface, so that the height through which the water had to be elevated was only 6.27 feet. The plant had been in operation several days and was stopped to measure the head. The remarks made in the case of the previous test apply equally well in this one.

The following is a detailed statement of the cost of this outfit:

Cost of wells and pits	$1,700
2 Kingsford pumps, at $200 each	400
Engine and boiler (second hand)	1,000
Shed	250
Belting	150
Total	3,500

When purchased the engine and boiler had been used but were almost new and were bought at a bargain. The shed was unusually large and contained more material than was necessary. The cost of belting was excessive because of the arrangement of the plant, one main belt being required between engine and jack shaft and two more between jack shafts and pumps.

Results of test of plant No. 8.

Duration of test, hours	2
Lift, feet	6.27
Average indicated horsepower	57.79
Average discharge of pumps, cubic feet per second	6.38
Average discharge of pumps, gallons per minute	2,878
Average discharge of pumps, acre-feet per hour	0.53
Fuel consumed per hour, pounds	403
Fuel consumed per indicated horsepower hour, pounds	7
Fuel consumed per acre-foot, pounds	760.4
Fuel consumed per foot-acre-foot, pounds	112.7
Cost of fuel per ton	$7.00
Cost of fuel per hour	$1.413
Cost of fuel per indicated horsepower hour	$0.0244
Cost of fuel per acre-foot	$2.68
Cost of fuel per foot-acre-foot	$0.428
Efficiency of engine, pumps, and well, per cent	7.9

COST OF WATER.

Cost of plant	$3,500
Area irrigated, acres	200
Cost of plant per acre irrigated	$17.50

ANNUAL COST PER ACRE.

Interest on first cost at 7 per cent	$1.23
Depreciation, 10 per cent of first cost	1.75
Fuel cost of 1.25 acre-feet	3.35
Attendance	1.40
Total annual cost per acre irrigated	7.73

PLANT NO. 9.

This plant is located about 1½ miles west of Lonoke, Ark., at the State Agricultural Experiment Station. The plant was installed in 1904 by the State of Arkansas in cooperation with the U. S. Department of Agriculture. During the season of 1907 45 acres was watered.

A noncondensing slide-valve engine is used, having a diameter of cylinder 8 inches, and diameter of rod $1\frac{7}{16}$ inches, and stroke 13 inches.

By means of a quarter-twist cotton belt the engine drives a vertical-shaft centrifugal pump placed in a pit 30 feet deep. The well is 100 feet deep with casing and 30 feet of copper-gauze strainer. The engine fly wheel is used as a pulley. It is 54 inches in diameter while the pump pulley is 14 inches in diameter.

The boiler is of the self-contained, horizontal, return-tubular type, shell 10 by 2 feet, $10\frac{1}{2}$ inches. There are twenty-six 3-inch tubes. The setting is built of bricks and the plant is in fairly good condition.

An injector is used to feed the boiler; there is no heater.

The test lasted for four hours; the conditions were fairly regular.

Coal was weighed in quantities of 45 pounds and the time of firing each charge noted. Indicator cards and general observations were taken at half-hour intervals. The quantity of water fed to the boiler was carefully weighed.

The water pumped was measured by means of a permanent 12-inch Cipolletti weir. The height of water over the crest was measured by means of a hook gauge.

The level of the water in the pit was known to be the same as that in the discharge of the pump when the pump was idle. The height of the discharge from that level was used as the head in computing useful water horsepower and efficiency as was done in the plants tested in Louisiana. On this basis the head was 27.6 feet.

The fuel used was bituminous coal, costing $3.40 per ton at the plant.

The cost of the entire plant, including machinery, shed, and well, was $1,800.

Results of test of plant No. 9.

Duration of test, hours	4
Lift, feet	27.6
Average indicated horsepower	17.2
Average discharge of pump, cubic feet per second	1.10
Average discharge of pump, gallons per minute	495
Average discharge of pump, acre-feet per hour	0.0913
Fuel consumed per hour, pounds	123.8
Fuel consumed per indicated horsepower hour, pounds	7.2
Fuel consumed per acre-foot, pounds	135.6
Fuel consumed per foot-acre-foot, pounds	49.1
Cost of fuel per ton	$3.40
Cost of fuel per hour	$0.211
Cost of fuel per indicated horsepower hour	$0.0123
Cost of fuel per acre-foot	$2.32
Cost of fuel per foot-acre-foot	$0.0842
Efficiency of engine, pump, and well, per cent	20

COST OF WATER.

Cost of plant	$1,800
Area irrigated, acres	45
Cost of plant per acre irrigated	$40

ANNUAL COST PER ACRE.

Interest on first cost at 7 per cent	$2.80
Depreciation, 10 per cent of first cost	4.00
Fuel cost of 1.25 acre-feet	2.90
Attendance	6.22
Total annual cost per acre irrigated	15.92

PLANT NO. 10.

On August 20, 1907, the well pumping plant belonging to Mr. W. H. Hicks, located about 5 miles southeast of Lonoke, Ark., was tested. Ninety-two acres of rice was watered during the season of 1907.

The well is 168 feet deep; the casing is 10 inches in diameter and has 70 feet of sawed strainer. The pump is a No. 6 vertical-shaft centrifugal, placed in a pit 40 feet deep.

The engine has a 10-inch cylinder with a 12-inch stroke; diameter of rod, $1\frac{5}{8}$ inches.

The boiler is a horizontal return-tubular, 14 feet long by 44 inches in diameter, having twenty-eight 3-inch tubes. The setting is of brick. The furnace was in bad condition, due to cracks in the front of the setting, causing several large leaks. An injector was used to feed the boiler; there was no feed-water heater.

The fuel used was wood, costing $1.50 per cord, and bituminous coal, costing $4 per ton of 2,000 pounds at the plant.

The water pumped was measured by means of a portable 18-inch Cipolletti weir placed in the discharge ditch.

During the test the water used was carefully weighed, as was also the coal. The wood used was measured. General observations as noted in the log were taken at half-hour intervals. The test lasted for $2\frac{1}{2}$ hours. All the conditions were uniform and the results entirely satisfactory.

The height through which the water was elevated was measured, as in the other tests, by means of a steel tape in the discharge pipe of the pump. It was 35.8 feet. The plant had been running for several days and was stopped only long enough to measure the head.

This plant could cut down fuel expense 10 per cent by installing a heater. The mean temperature of feed was only 60.5° F. A heater could be employed to raise the temperature over 100° and not only effect a saving in fuel, but also prolong the life of the boiler by avoiding stresses due to wide variations in the temperature of the water in its different parts.

The total cost of this plant was as follows:

Well, pit, and pump	$1,000
Engine and boiler	1,100
Total	2,100

Results of test of plant No. 10.

Duration of test, hours	3
Lift, feet	35.8
Average indicated horsepower	41.7
Average discharge of pump, cubic feet per second	1.64
Average discharge of pump, gallons per minute	738
Average discharge of pump, acre-feet per hour	0.136
Cost of fuel—	
Coal, per ton	$4.00
Wood, per cord	$1.50
Cost of fuel per hour	$0.312
Cost of fuel per indicated horsepower hour	$0.0075
Cost of fuel per acre-foot	$2.30
Cost of fuel per foot-acre-foot	$0.0642
Efficiency of engine, pump, and well, per cent	16.1

COST OF WATER.

Cost of plant	$2,100
Area irrigated, acres	92
Cost of plant per acre irrigated	$22.82

ANNUAL COST PER ACRE.

Interest on first cost at 7 per cent	$1.60
Depreciation, 10 per cent on first cost	2.28
Fuel cost of 1.25 acre-feet	2.88
Attendance	3.04
Total annual cost per acre irrigated	9.80

PLANT NO. 11.

The plant owned by Mr. E. M. Coppage, located about 5 miles south of Lonoke, Ark., was tested August 21, 1907.

There are two 8-inch wells, 156 and 158 feet deep, respectively, each having 60 feet of sawed strainer. From these wells 110 acres of rice was watered in 1907.

The wells are pumped by means of an air compressor. It is a horizontal machine with air cylinder 19 inches in diameter, arranged in tandem, with the steam cylinder 12 inches in diameter. The length of stroke is 14 inches. Cross head and connecting rod connect the pistons to a crank on the main shaft. Two heavy fly wheels are provided, so that the steam is used expansively. A variable cut-off, capable of adjustment while the engine is running, controls the speed. During the test the cut-off was at approximately half stroke.

Air is pumped into a large cylindrical receiver in which an average pressure of 36 pounds is maintained, from which it is conducted to the two wells. Each well is provided with 100 feet of 1½-inch pipe,

placed within the 8-inch casing. At the bottom of the air pipe is a fitting which reverses the direction of the air, allowing it to leave the pipe in the direction of the flow of the water. Of course a pit is not necessary in this case.

As in the other tests, the height through which the water was elevated was measured by means of a tape in the well casing. It was found to be 38.5 feet in one case and 36.6 feet in the other, the inequality being due to the varying height the two casings project above the level of the ground. As the water from both wells was measured in one flume, the mean height, 37.5 feet, was used in computing useful water horsepower and efficiency. A current meter was used to measure the velocity of the water in a small flume placed in the discharge ditch.

The fuel used at this plant was bituminous coal, costing $4.50 per ton of 2,000 pounds at the plant. During the test the coal used was carefully weighed.

Feed water is forced into the boiler at practically the temperature at which it comes from the well, as no heater is provided.

The test lasted for only three hours; conditions were uniform throughout.

The indicator cards show that the exhaust from the steam cylinder of this air compressor opened when the steam pressure had reached a pressure of about 36 pounds on the expansion line. At this pressure each pound of saturated steam contains enough heat above the temperature of feed to raise the temperature of 1,134 pounds of water 1°. A larger steam cylinder, which would expand the steam to a lower terminal pressure before exhaust, would be more economical of steam. In any case a feed-water heater should be provided to utilize a part of the heat from the steam that otherwise is thrown away in the exhaust.

The cost of this pumping plant was as follows:

2 wells, at $550 each	$1,100
Boiler, engine, and air compressor	2,100
Engine house	150
Total	3,350

Results of test of plant No. 11.

Duration of test, hours	3
Lift, feet	37.5
Average indicated horsepower	57.6
Average discharge of pump, cubic feet per second	1.96
Average discharge of pump, gallons per minute	882
Average discharge of pump, acre-feet per hour	0.163
Fuel consumed per hour, pounds	258.3
Fuel consumed per indicated horsepower hour, pounds	4.48
Fuel consumed per acre-foot, pounds	1,523.3
Fuel consumed per foot-acre-foot, pounds	40.6
Cost of fuel per ton	$4.50

Cost of fuel per hour	$0.58
Cost of fuel per indicated horsepower hour	$0.0101
Cost of fuel per acre-foot	$3.57
Cost of fuel per foot-acre-foot	$0.0952
Efficiency of engine, pump, and well, per cent	19.6

COST OF WATER.

Cost of plant	$3,350
Area irrigated, acres	110
Cost of plant per acre irrigated	$30.46

ANNUAL COST PER ACRE.

Interest on first cost at 7 per cent	$2.13
Depreciation, 10 per cent on first cost	3.05
Fuel cost of 1.25 acre-feet	4.46
Attendance	2.55
Total annual cost per acre irrigated	12.19

PLANT NO. 12.

The pumping plant owned by Mr. Frank Brass, located about 6 miles south of Carlisle, Ark., was tested on August 22, 1907. It was used to water 72 acres of rice in 1907.

The well is 142 feet deep and is provided with 60 feet of strainer, of which 20 feet is sawed and 40 feet wire-wrapped. The pump is a vertical-shaft centrifugal, placed in a pit about 30 feet deep. The impeller of the pump was slightly above the level of the water in the well, so that it was necessary to prime the pump when it was started.

Power is transmitted to the pump by means of a quarter-twist belt from a 10 by 16 inch engine.

Steam is furnished by a horizontal return-tubular boiler, 14 feet long by 48 inches in diameter. There are thirty-six 3½-inch tubes. The boiler setting is built of bricks. There is no feed-water heater.

Wood costing $1.50 per cord and coal costing $3.85 per ton of 2,000 pounds at the plant were the fuels used.

Fuel was measured for three hours. The test of the engine and pump lasted for 2½ hours. Conditions were irregular because the steam pressure was allowed to vary widely.

The water pumped was measured by means of a portable wooden Cipolletti weir, placed in the discharge ditch leading from a pond into which the pump discharged. Some time was required for any change of quantity of water to be shown at the weir on account of the large area of the pond.

The cost of this plant was as follows:

Well and casing	$514
Boiler, engine, and pump	1,140
Pit (labor and lumber)	125
Cost of erection	160
Total	1,939

Results of test of plant No. 12.

Duration of test, hours	2.5
Lift, feet	29.6
Average indicated horsepower	32.7
Average discharge of pump, cubic feet per second	2.03
Average discharge of pump, gallons per minute	927
Average discharge of pump, acre-feet per hour	0.168
Cost of fuel—	
Coal, per ton	$3.85
Wood, per cord	$1.50
Cost of fuel per hour	$0.42
Cost of fuel per indicated horsepower hour	$0.0129
Cost of fuel per acre-foot	$2.50
Cost of fuel per foot-acre-foot	$0.0846
Efficiency of engine, pump, and well, per cent	19.6

COST OF WATER.

Cost of plant	$1,939
Area irrigated, acres	72
Cost of plant per acre irrigated	$26.93

ANNUAL COST PER ACRE.

Interest on first cost at 7 per cent	$1.89
Depreciation, 10 per cent on first cost	2.69
Fuel cost of 1.25 acre-feet	3.13
Attendance	3.89
Total annual cost per acre irrigated	11.60

PLANT NO. 13.

On August 23, 1907, a test was made of the pumping plant of Mr. C. E. Smiley, located about 2½ miles east of Carlisle, Ark. This outfit furnished water for irrigating 100 acres of rice in 1907.

An air compressor exactly like the one described in plant No. 11 is used. The air and steam cylinders are 19 inches and 12 inches in diameter, respectively, and the stroke 14 inches. There is a large cylindrical tank which acts as a receiver for the compressed air, the mean pressure maintained in the tank being 39.6 pounds. From this tank the air is conducted to the two wells, each of which has 125 feet of 1½-inch air pipe. The wells are each 8 inches in diameter; one is 150 feet deep and the casing projects 5 feet above the surface. The plant was run for the first time during the season of 1906 and this well only was used. The other well, which was added this year, is 135 feet deep and the casing also projects 5 feet above the ground. The deeper well has 60 feet of sawed strainer and is closed at the bottom, while the other well has only 17½ feet of sawed strainer, which, however, is coarser than that in the other well, and the bottom of the pipe is open.

The discharge could be measured from the deeper well only. This was done by means of a small weir with end contractions suppressed,

placed across the discharge flume. As nearly as could be judged by observation, the two wells were throwing about the same amount of water. At any rate, it was impossible to measure the water from both wells, as each discharged separately into a canal of comparatively large cross section and slow velocity, and only one hook gauge was available. In computing results it is assumed that the discharge from the two wells is equal. The head was measured in the well casings by means of a steel tape and was found to be approximately the same in the two cases, the average being 51.3 feet.

The boiler is a horizontal return-tubular, 14 feet by 54 inches. There are forty-six $3\frac{1}{2}$-inch tubes.

No feed-water heater is used; it would be of material advantage if one were added to the equipment of the plant.

The boiler pressure averaged 15 pounds higher than in test No. 11. The revolutions per minute were also greater and the cut-off, as shown by the cards, only about one-third stroke.

The fuel used was bituminous coal, costing $2.95 per ton of 2,000 pounds. The plant is favorably located on the railroad, which reduces cost of handling to a minimum.

The cost of this plant was as follows:

Machinery	$2,000
Wells (no pit required)	963
Total	2,963

Results of test of plant No. 13.

Duration of test, hours	3
Lift, feet	51.3
Average indicated horsepower	64.5
Average discharge of pump, cubic feet per second	1.68
Average discharge of pump, gallons per minute	756
Average discharge of pump, acre-feet per hour	0.139
Fuel consumed per hour, pounds	208
Fuel consumed per indicated horsepower hour, pounds	3.22
Fuel consumed per acre-foot, pounds	1,496.4
Fuel consumed per foot-acre-foot, pounds	29.1
Cost of fuel per ton	$2.95
Cost of fuel per hour	$0.307
Cost of fuel per indicated horsepower hour	$0.0047
Cost of fuel per acre-foot	$2.22
Cost of fuel per foot-acre-foot	$0.0432
Efficiency of engine, pump, and well, per cent	15.2

COST OF WATER.

Cost of plant	$2,963.00
Area irrigated, acres	100
Cost of plant per acre irrigated	$29.63

ANNUAL COST PER ACRE.

Interest on first cost at 7 per cent	$2.07
Depreciation, 10 per cent on first cost	2.96
Fuel cost of 1.25 acre-feet	2.78
Attendance	2.80
Total annual cost per acre irrigated	10.61

PLANT NO. 14.

This pumping plant, tested on August 24, 1907, is the property of Mr. D. B. Perkins. It is located about 2½ miles south of Carlisle and furnished water for 240 acres of rice during the season of 1907.

There are two wells. Well No. 1 has 57 feet of 8-inch sawed strainer and a vertical centrifugal pump; diameter of discharge pipe, 8⅛ inches; depth of pit, 34 feet; height through which water was lifted, 36.8 feet. Well No. 2 has 60 feet of 10-inch perforated strainer and a vertical centrifugal pump; diameter of discharge pipe, 9⅝ inches; depth of pit, 38 feet; lift, 36.8 feet. The perforations in the strainer of well No. 2 are made by forcing a sharp point through the casing after it is set in the well.

The wells, and consequently the pumps, are 60 feet apart. A jack shaft a little more than 60 feet long is belted to the pumps by quarter-twist belts. Pump No. 1 has a pulley 14 inches in diameter, while the pulley on the jack shaft used to drive it is 36 inches in diameter. Pump No. 2 has a 16-inch pulley which is driven from a 36-inch pulley on the jack shaft.

An 11 by 16 inch noncondensing slide-valve engine with fly wheel 60 inches in diameter is belted to a 40-inch pulley on the jack shaft.

The boiler is of the horizontal return-tubular type, 14 feet in length by 54 inches in diameter, having sixty-eight 3-inch tubes. The setting is built of brick.

The fuel used is Kentucky bituminous coal, costing $3.60 per ton of 2,000 pounds at the plant.

A closed heater having corrugated copper tubes is used to heat the feed water by means of exhaust steam.

The engine is used to drive either pump separately or both together. A complete test of boiler, engine, and pump No. 1 was run for three hours. The belt between the jack shaft and pump No. 1 was then removed and pump No. 2 was belted to the jack shaft and two sets of readings of steam pressure, revolutions per minute of engines and pumps, and the amount of water pumped were observed. Finally, both pumps were belted to the jack shaft and two sets of readings taken with both pumps in operation.

During the first test the water fed to the boiler and the amount of coal consumed were carefully weighed.

The water pumped was measured in each case by means of a portable 18-inch Cipolletti weir placed in the discharge ditch. The depth of water on the crest of the weir was measured by means of a hook gauge. As the pumps discharged into a large pond, it was necessary to establish uniform conditions by running at a uniform rate for some time previous to taking readings.

It was impossible to maintain the speed of the engine when driving the two pumps, and the quantity pumped was only 3.27 cubic feet per second, as against 2.03 for pump No. 1 and 2.46 for pump No. 2, or 1.61 times the amount furnished by pump No. 1 and 1.33 times the amount furnished by pump No. 2.

The belts were removed between the jack shaft and pumps and a set of indicator cards taken to obtain the friction of engine and jack shaft. This card showed that 6.8 horsepower were required at 209 revolutions per minute for the engine. This, however, is at a higher rate of speed than that used during the test.

The cost of this pumping plant was as follows:

Boiler, engine, and fittings	$1,100
Two pumps	275
Heater	116
Two wells and pits	1,500
Material and labor used in erecting plant	250
Total	3,241

Results of test of plant No. 14.

Duration of test, hours	3
Lift, feet	36.8
Average indicated horsepower	42.3
Average discharge of pump, cubic feet per second	2.03
Average discharge of pump, gallons per minute	914
Average discharge of pump, acre-feet per hour	0.168
Fuel consumed per hour, pounds	270
Fuel consumed per indicated horsepower hour, pounds	6.38
Fuel consumed per acre-foot, pounds	1,607.1
Fuel consumed per foot-acre-foot, pounds	43.7
Cost of fuel per ton	$3.60
Cost of fuel per hour	$0.486
Cost of fuel per indicated horsepower hour	$0.0115
Cost of fuel per acre-foot	$2.90
Cost of fuel per foot-acre-foot	$0.0788
Efficiency of engine, pump, and well, per cent	20

COST OF WATER.

Cost of plant	$3,241.00
Area irrigated, acres	240
Cost of plant per acre irrigated	$13.50

ANNUAL COST PER ACRE.

Interest on first cost, at 7 per cent	\$0.95
Depreciation, 10 per cent on first cost	1.35
Fuel cost of 1.25 acre-feet	3.63
Attendance	1.17
Total annual cost per acre irrigated	7.10

PLANT NO. 15.

On August 26, 1907, a test was made of the pumping plant of Mr. G. W. Fagan, located 1 mile west of Stuttgart, Ark. This plant furnished water for 115 acres of rice during the season of 1907.

The well is 130 feet deep. The casing is $9\frac{5}{8}$ inches in diameter, with 60 feet of sawed strainer. The pit is 33 feet deep.

The pump used is a vacuum pump, having a suction pipe 6 inches in diameter and discharge pipe 5 inches in diameter. There are two cast-iron cylinders, into which steam is admitted alternately to drive out the water. After the admission valve has closed, the charge of steam remaining in the cylinder is condensed by a spray of water and water rises in the well to partially fill the vacuum formed. Steam is again admitted to top of the water, driving it out through a discharge pipe. While one cylinder is filling the other is emptying. The valves are opened and closed at the proper interval by means of a very small steam engine placed above the surface of the ground, while the pump cylinders are placed at the bottom of the pit.

Steam is furnished by a horizontal return-tubular boiler, length 14 feet and diameter 48 inches, having thirty-six $3\frac{1}{2}$-inch tubes. An injector is used to feed the boiler. A regulating valve, placed in the steam main, is used to keep the pressure at the pump at 60 pounds per square inch.

The fuel used was Arkansas bituminous run-of-mine coal, costing \$3.80 per ton of 2,000 pounds at the plant.

The quantity of water pumped was measured by means of the portable 18-inch Cipolletti weir. The depth of water over the crest was measured by means of a hook gauge.

The test lasted for four hours, during which the amount of coal used, water fed to the boiler, steam pressure, pulsations per minute, and reading of hook gauge were recorded. The results of the test are given in the log.

This type of pump is considered by some to be much simpler than those previously described.

The cost of this plant was as follows:

Boiler	\$500
Pump	700
Well	650
Pit	200
Shed	150
Total	2,200

Results of test of plant No. 15.

Duration of test, hours	4
Lift, feet	34.2
Average discharge of pump, cubic feet per second	0.836
Average discharge of pump, gallons per minute	376
Average discharge of pump, acre-feet per hour	0.069
Fuel consumed per hour, pounds	162.5
Fuel consumed per acre-foot, pounds	2,355.1
Fuel consumed per foot-acre-foot, pounds	68.86
Cost of fuel per ton	$3.80
Cost of fuel per hour	$0.309
Cost of fuel per acre-foot	$4.48
Cost of fuel per foot-acre-foot	$0.131
COST OF WATER.	
Cost of plant	$2,200
Area irrigated, acres	115
Cost of plant per acre irrigated	$19.13
ANNUAL COST PER ACRE.	
Interest on first cost, at 7 per cent	$1.34
Depreciation, 10 per cent of first cost	1.91
Fuel cost of 1.25 acre-feet	5.60
Attendance	1.87
Total annual cost per acre irrigated	10.72

PLANT NO. 16.

The pumping plant owned by Dr. O. C. Strothers, located 7½ miles southwest of Stuttgart, Ark., was tested on August 27. Seventy acres of rice was watered during the season of 1907.

The well is 112 feet deep and has 10-inch casing with two lengths of sawed strainer aggregating 37 feet in length.

A pitless pump, consisting of a series oi screw-shaped impellers of sufficiently small diameter to fit into the casing, is used. The bearings for the shaft are leaf springs which press against the inside of the casing. There are seven 10-foot lengths of impellers, or 70 feet in all. Owing to the small diameter of the impellers the pump is run at a very high speed, the average during the 4-hour test being 1,123 revolutions per minute.

The engine is a 12 by 14 inch slide-valve. A quarter-twist belt was used to drive the pump. The engine was in very bad condition, having gone through a fire and not having been thoroughly overhauled afterwards. The friction was so great that two men and a long pry were required to turn the wheel over. A set of friction cards for engine with belt removed were taken at the end of the test and showed the friction horsepower to be 8.6, or 15.3 per cent of the mean horsepower during the test.

The boiler is a horizontal return tubular, shell 4 feet by 54 inches, with forty 3½-inch tubes. The setting is built of bricks. An injector is used to feed the boiler.

The fuel is bituminous coal, costing $4 per ton of 2,000 pounds delivered at the plant.

During the test the coal and feed water were carefully weighed. The other observations noted in the log were taken at half-hour intervals for four hours.

The height through which the water was pumped was measured by means of a tape with a weight attached, let down through the pump until the water was reached, the point being noted by the splash of the weight in the water.

The discharge water was measured by means of a current meter in a small flume. The observations were taken on the quarter hour, while other observations were taken on the half hours and hours.

The engine and boiler were bought secondhand, after having been damaged by fire. The cost was as follows:

Engine and boiler	$700
Pump	100
Well (no pit required)	600
Cost of erecting plant	200
Total	1,600

Had the engine and boiler been purchased new they would probably have cost from $500 to $800 more.

Results of test of plant No. 16.

Duration of test, hours	4
Lift, feet	32
Average indicated horsepower	56.2
Average discharge of pump, cubic feet per second	1.65
Average discharge of pump, gallons per minute	743
Average discharge of pump, acre-feet per hour	0.137
Fuel consumed per hour, pounds	362
Fuel consumed per indicated horsepower hour, pounds	6.44
Fuel consumed per acre-foot, pounds	2,642.3
Fuel consumed per foot-acre-foot, pounds	82.6
Cost of fuel per ton	$4.00
Cost of fuel per hour	$0.724
Cost of fuel per indicated horsepower hour	$0.0129
Cost of fuel per acre-foot	$5.31
Cost of fuel per foot-acre-foot	$0.166
Efficiency of engine, pump, and well, per cent	10.7

COST OF WATER.

Cost of plant	$1,600
Area irrigated, acres	70
Cost of plant per acre irrigated	$22.86

ANNUAL COST PER ACRE.

Interest on first cost, at 7 per cent	$1.60
Depreciation, 10 per cent of first cost	2.29
Fuel cost of 1.25 acre-feet	5.44
Attendance	4.00
Total annual cost per acre irrigated	13.33

PLANT NO. 17.

A test of the pumping plant of Mr. S. J. Powell, located 5 miles south of Stuttgart, Ark., was made on August 28, 1907. It furnished water for 80 acres of rice during the season of 1907.

The well is 230 feet deep and has 10-inch casing, with 19 feet of sawed and 17 feet of wire-wrapped strainer.

The outfit consists of a vacuum pump of the same type and size as that described in test No. 15, with 6-inch suction pipe and 5-inch discharge pipe, and horizontal return tubular boiler 14 feet long by 54 inches in diameter, with forty-six 3-inch tubes. The setting is built of bricks. An injector is used to feed the boiler.

The fuel used is coal, costing $3.80 per ton of 2,000 pounds delivered at the plant.

The water pumped was measured by means of an 18-inch portable Cipolletti weir. The height of water over the crest was obtained by using a hook gauge. The head was measured by means of a tape.

During the test the coal used and the feed water were carefully weighed. The other observations given in the log were taken at half-hour intervals. The test lasted for only three hours, but the conditions were probably as uniform and the results as reliable as could be obtained from a longer run.

The height through which the water was raised was 51 feet.

The cost of the plant was as follows:

Boiler	$600
Pump and piping	878
Shed	75
Well and pit	652
Total	2,205

Results of test of plant No. 17.

Duration of test, hours	3
Lift, feet	51
Average discharge of pump, cubic feet per second	1.05
Average discharge of pump, gallons per minute	473
Average discharge of pump, acre-feet per hour	0.087
Fuel consumed per hour, pounds	293
Fuel cousumed per acre-foot, pounds	3,367.8
Fuel consumed per foot-acre-foot, pounds	66.0
Cost of fuel per ton	$3.80
Cost of fuel per hour	$0.557
Cost of fuel per acre-foot	$6.41
Cost of fuel per foot-acre-foot	$0.126

COST OF WATER.

Cost of plant	$2,205
Area irrigated, acres	80
Cost of plant per acre irrigated	$27.56

ANNUAL COST PER ACRE.

Interest on first cost, at 7 per cent	$1.93
Depreciation, 10 per cent of first cost	2.76
Fuel cost of 1.25 acre-feet	8.01
Attendance	3.50
Total annual cost per acre irrigated	16.20

PLANT NO. 18.

The pumping plant of Mr. D. Runyon, located about 4½ miles northeast of Stuttgart, Ark., was tested on August 29. During the season of 1907 55 acres of rice was irrigated by means of this plant.

The well is 155 feet deep and has 9⅝-inch casing with 56 feet of wire-wrapped strainer. The pump is a compound centrifugal with a vertical shaft, having 6-inch suction and 8-inch discharge pipe.

The engine is a 12 by 14 inch noncondensing slide-valve and drives the pump by means of a quarter-twist belt.

The boiler is a horizontal return tubular, shell 15 feet 3 inches by 54 inches. There are forty-four 3½-inch tubes. The setting is a steel casing. An injector is used to feed the boiler and there is no feed-water heater.

The fuel used is bituminous coal, costing $4.35 delivered at the plant.

An 18-inch Cipolletti weir was used to measure the discharge.

An attempt was made to weigh coal and water and to make a test of sufficient length to be fairly reliable.

Difficulties were experienced that made the weighing of water impossible, and the breaking of the belt brought the test to an abrupt close at the end of an hour.

As there was no way to accurately measure down to the water level, the head pumped against had to be estimated so that the test was extremely unreliable.

When the well was bored the water was found to be 49 feet below the surface of the ground. The assumed head of 55 feet was taken because the level had fallen somewhat as the pumping season progressed. The pump was placed 64 feet below the surface, and there was a 14-foot suction pipe extending down into the well casing. When the pump was run at high speed it drew the water down so that air entered the suction pipe. This means that the total lift was then 78 feet. To prevent the pump from taking air another 14 feet length of section pipe was added, and no more trouble was had with air. These facts are of interest, as they show that the true head against which a pump is acting is greatly increased by high speed

when a demand is made on the well for a large amount of water. It still further emphasizes the fact that each pump should be, whenever possible, supplied with a vacuum gauge on the suction pipe so that conditions can be better known.

The cost of this pumping plant complete was $3,500.

Results of test of plant No. 18.

Duration of test, hours	1.45
Lift, feet	55
Average indicated horsepower	65.3
Average discharge of pump, cubic feet per second	2.04
Average discharge of pump, gallons per minute	918
Average discharge of pump, acre-feet per hour	0.169
Fuel consumed per hour, pounds	372
Fuel consumed per indicated horsepower hour, pounds	5.7
Fuel consumed per acre-foot, pounds	2,201.2
Fuel consumed per foot-acre-foot, pounds	40
Cost of fuel per ton	$4.35
Cost of fuel per hour	$0.812
Cost of fuel per indicated horsepower hour	$0.0124
Cost of fuel per acre-foot	$4.81
Cost of fuel per foot-acre-foot	$0.088
Efficiency of engine, pump, and well, per cent	19.5
COST OF WATER.	
Cost of plant	$3,500
Area irrigated, acres	55
Cost of plant per acre irrigated	$63.64
ANNUAL COST PER ACRE.	
Interest on first cost at 7 per cent	$4.45
Depreciation, 10 per cent of first cost	6.36
Fuel cost of 1.25 acre-feet	6.01
Attendance	5.10
Total annual cost per acre irrigated	21.92

SUMMARY OF RESULTS OF TESTS OF WELL PLANTS.

The tests made in 1907 cover a wide range of territory with varying conditions as regards lifts, types of pumps, and kinds of fuel used. The peculiarities of the tests have been noted in each case. The fuels used were wood, coal, and crude oil, the oil being used in Louisiana only. Assuming that rates of interest and depreciation are the same and that the same quantity of water is required in the two sections—$1\frac{1}{4}$ acre-feet per acre for the season—and that the cost of attendance is uniform, the total cost per acre irrigated may be compared. In the following table the cost of pumping in the two districts is summarized.

Summary of results of tests of well pumping plants.

LOUISIANA.

Plant No.	Lift.	First cost.	Area irrigated.	First cost per acre irrigated.	Fixed charges per acre irrigated.	Fuel cost per acre irrigated.	Attendance per acre irrigated.	Total annual cost per acre irrigated.
			Acres.					
2	17.50	$2,668	140	$19.06	$3.33	$2.03	$2.00	$7.36
3	23.86	2,200	300	7.33	1.24	2.93	.93	5.10
4	27.00	4,404	230	19.15	3.26	4.25	1.22	8.73
5	33.25	3,300	175	18.86	3.21	1.78	1.60	6.59
6	21.00	2,500	140	17.86	3.04	2.68	2.00	7.72
7	7.81	2,524	165	15.30	2.60	2.34	1.71	6.65
8	6.27	3,500	200	17.50	2.98	2.35	1.40	7.73
Total and average	19.53	21,096	1,350	15.63	2.66	2.56	1.45	6.67

ARKANSAS.

Plant No.	Lift.	First cost.	Area irrigated.	First cost per acre irrigated.	Fixed charges per acre irrigated.	Fuel cost per acre irrigated.	Attendance per acre irrigated.	Total annual cost per acre irrigated.
9	27.60	$1,800	45	$40.00	$6.80	$2.90	$6.22	$15.92
10	35.80	2,100	92	22.82	3.88	2.88	3.04	9.80
11	37.50	3,350	110	30.48	5.18	4.46	2.55	12.19
12	29.60	1,939	72	26.93	4.58	3.13	3.89	11.60
13	51.30	2,963	100	29.63	5.03	2.78	2.80	10.61
14	36.80	3,241	240	13.50	2.30	3.63	1.17	7.10
15	34.20	2,200	115	19.13	3.25	5.60	1.87	10.72
16	32.00	1,600	70	22.86	3.89	5.44	4.00	13.33
17	51.00	2,205	80	27.56	4.69	8.01	3.50	16.20
18	55.00	3,500	55	63.64	10.81	6.01	5.10	21.92
Total and average	39.80	24,898	979	25.43	4.32	4.43	2.86	11.61

The table shows that the average cost of pumping at the well plants tested in Louisiana is $6.67 per acre, while that at the Arkansas plants is $11.61 per acre irrigated. The average lift at the Louisiana plants is approximately 20 feet, and at the Arkansas plants approximately 40 feet, the increase in cost not being quite proportional to the increase in lift. Although the Arkansas rice planters secure their water supply at a slightly smaller cost per acre per foot of lift, yet they must contend against a considerably higher cost of water than that borne by the Louisiana planters, due entirely to the increased lift.

Coming to the comparison between taking water from a canal company in Louisiana and installing and operating a pumping plant large enough for a farm of ordinary size, in discussing this matter in a former report[a] the writer said, in substance: "Assume an 8-barrel crop and that the average price of rice is $3 per barrel. In case water is taken from a canal system, the charges of the canal company will be $\frac{1}{5} \times 8 \times \$3 = \$4.80$ per acre. With rice selling at $2.50 per barrel the amount paid the canal company would amount to $4. When the farmer raises a 10-barrel crop, and the price is $3 per barrel, the cost will be $6, while if the price of rice is $2.50, the water for the 10-barrel crop will cost $5." The average cost of pumping per acre in Louisiana, as shown by the table, is $6.67. This is based on the pumping of $1\frac{1}{4}$ acre-feet per acre. If more water is used the

[a] U. S. Dept. Agr., Office of Experiment Stations Bul. 183, p. 65.

cost will be approximately $2 additional per acre-foot used. It appears, then, that under ordinary conditions there is a slight financial advantage in securing water from a canal. Under abnormal conditions there are advantages on either side, and it is a matter of balancing these. In years of heavy rainfall and good crops the canal company secures its share of the crop for a minimum of service. Under the same circumstances the owner of a pumping plant saves his fuel charges. His interest is the same and his depreciation is nearly as great as in years when his plant is in full operation. On the basis of the plants shown in the table, the cost, if no pumping is done, will be $2.66 per acre, and the owner would gain the difference between this and the payments to the company. On the other hand, in case of crop failure for any reason, there are no payments to the canal company, while the cost to the pump owner will still be $2.66 per acre in addition to whatever is spent for fuel and attendance. This comes at a time when he has no crop from which to meet it, while the increased payments to the canal company come at a time when he is best able to bear them.

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